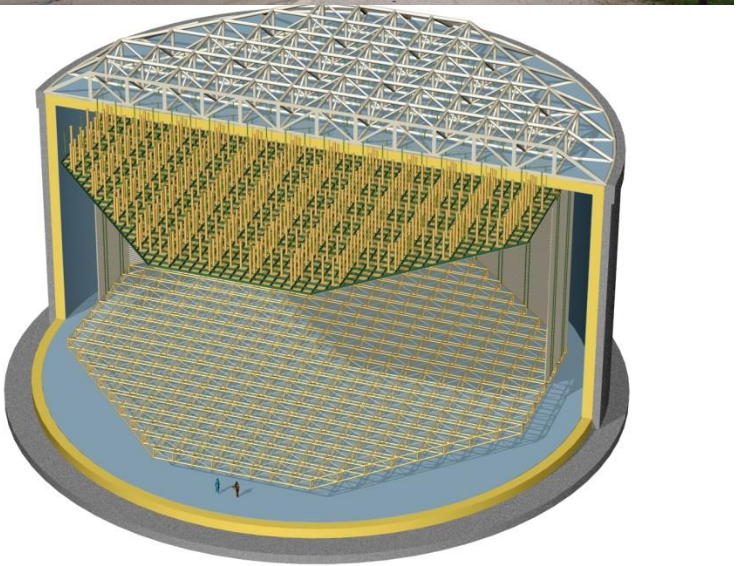
LBNO--What has been learned for a Fermilab hosted experiment?

iiEB meeting, Fermilab, 23 September 2014

D. Autiero (IPNL Lyon)



Outline:

1) The P5 report

(the origin of LBNF)

2) The LBNO world

(the general interest of its outcome/achievements for LBNF)

- *The LAGUNA-LBNO design study:*
  technological developments/costs optimizations for large underground detectors, staging/costing
- *The LBNO-DEMO/WA105 experiment at CERN:*
  a clear path for the detector technology demonstration
- *A PILOT experiment*
- *Physics strategy:*
  Mass Hierarchy
  Use of second maximum and spectral information for CP
  complementarity, systematics

3) LBNF as seen/being learnt from the LBNO community

(the LBNF opportunity and the IIEB process)

Experimental requirements, LBNE

Neutrino Oscillation Experiments (Long Baseline)

- For a long-baseline oscillation experiment, based on the science Drivers and what is practically achievable in a major step forward, we set as the goal a mean sensitivity to CP violation of better than 3σ (corresponding to 99.8% confidence level for a detected signal) over more than 75% of the range of possible values of the unknown CP-violating phase δ_{CP}.
  - By current estimates, this corresponds to an exposure of 600 kt*MW*y assuming systematic uncertainties of 1% and 5% for the signal and background, respectively. With a wideband neutrino beam produced by a proton beam with power of 1.2 MW, this implies a far detector with fiducal mass of more than 40 kilotons (kt) of liquid argon (LAr) and a suitable near detector.
- **The minimum requirements to proceed are the identified capability to reach an exposure of at least 120 kt*MW*yr by the 2035 timeframe, the far detector situated underground with cavern space for expansion to at least 40 kt LAr fiducial volume, and 1.2 MW beam power upgradable to multi-megawatt power. The experiment should have the demonstrated capability to search for supernova (SN) bursts and for proton decay, providing a significant improvement in discovery sensitivity over current searches for the proton lifetime.**

These minimum requirements are not met by the current LBNE project's CD-1 minimum scope.

A more ambitious experiment, designed and supported by the international neutrino community

Neutrino Oscillation Experiments (LBNF)

- The long-baseline neutrino program plan has undergone multiple significant transformations since the 2008 P5 report. Formulated as a primarily domestic experiment, the minimal CD-1 configuration with a small, far detector on the surface has very limited capabilities.
- A more ambitious long-baseline neutrino facility has also been urged by the Snowmass community study and in expressions of interest from physicists in other regions.
- To address even the minimum requirements specified above, **the expertise and resources of the international neutrino community are needed.**

- **A change in approach is therefore required**: The activity should be reformulated under the auspices of a new international collaboration, as an internationally coordinated and internationally funded program, with Fermilab as host. There should be international participation in defining the program's scope and capabilities. The experiment should be designed, constructed, and operated by the international collaboration. The goal should be to achieve, and even exceed if physics eventually demands, the target requirements through the broadest possible international participation.

Form a new international collaboration to meet the P5 requirements, LBNF is the highest priority project

Neutrino Oscillation Experiments (LBNF)

- Key preparatory activities will converge over the next few years: in addition to the international reformulation described above, PIP-II design and project definition will be nearing completion, as will the necessary refurbishments to the Sanford Underground Research Facility. Together, these will set the stage for the facility to move from the preparatory to the construction phase around 2018. The peak in LBNF construction will occur after HL-LHC peak construction.

- **Recommendation 13: Form a new international collaboration to design and execute a highly capable Long-Baseline Neutrino Facility (LBNF) hosted by the U.S. To proceed, a project plan and identified resources must exist to meet the minimum requirements in the text. LBNF is the highest-priority large project in its timeframe.**

P5 Report May 2014

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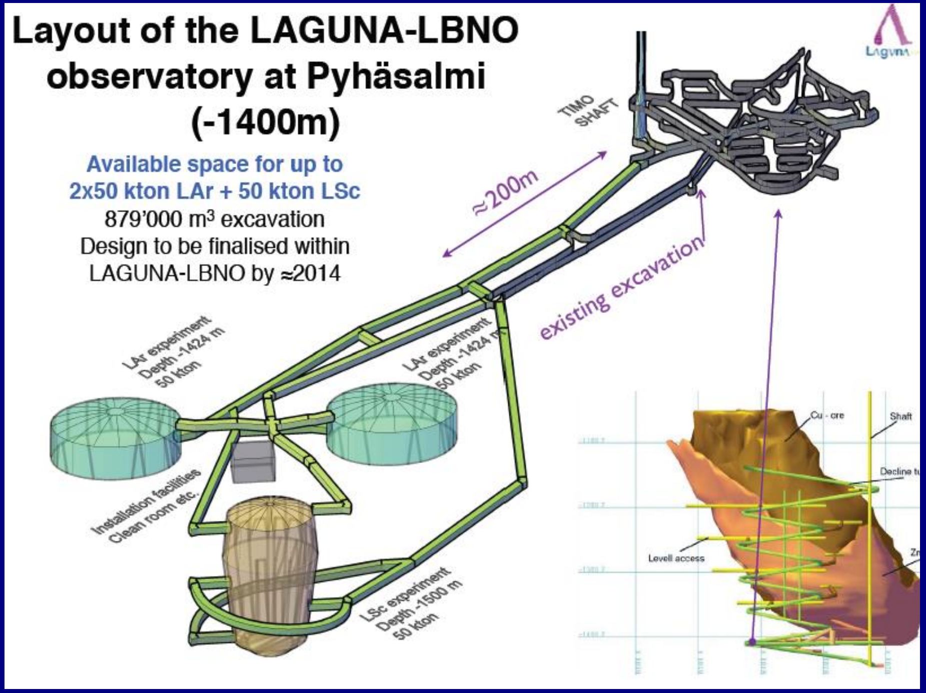
LAGUNA-LBNO:

A very long baseline neutrino experiment
2 EU programs: 2008-2011/2011-2014
~17 Meuro investment

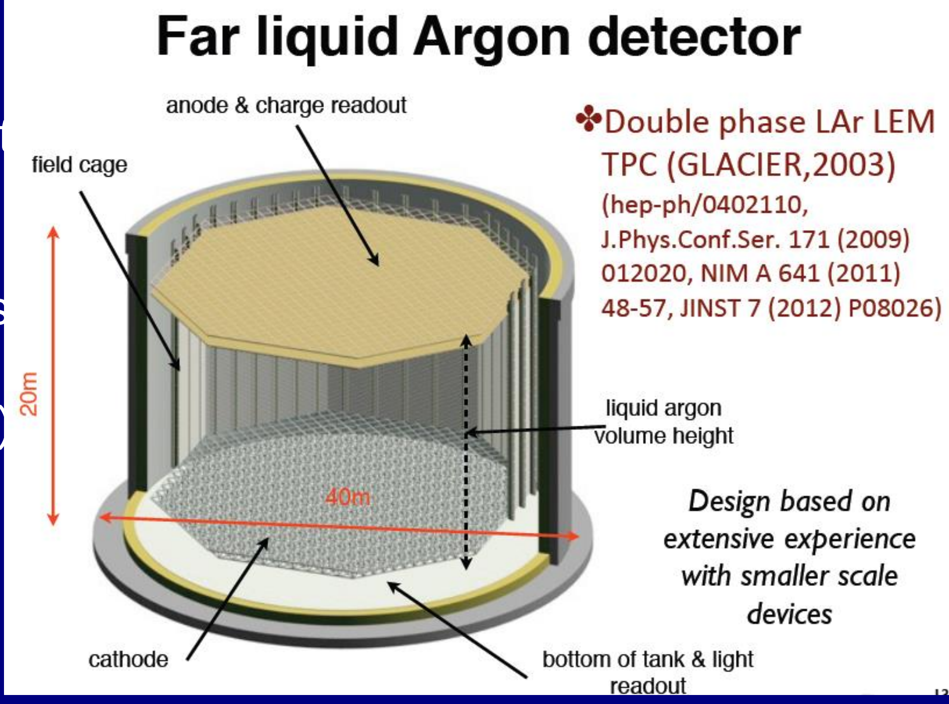
CERN EOI June 2012
http://cdsweb.cern.ch/record/1457543
224 physicists, 52 institutions
Physics program:

- Determination of neutrino mass hierarchy
- Search for CP violation
- Proton decay
- Atmospheric and supernovae neutrinos



LBNO Phase I:
the only experiment capable of guaranteeing unambiguous mass hierarchy determination (>5σ)

20 kton double phase LAr TPC



Industrial partners

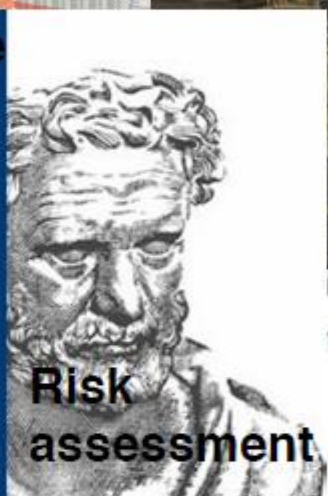
France
Sofregaz

UK
Alan Aul
GROUP LTD

U
RHYAL ENGINEERING

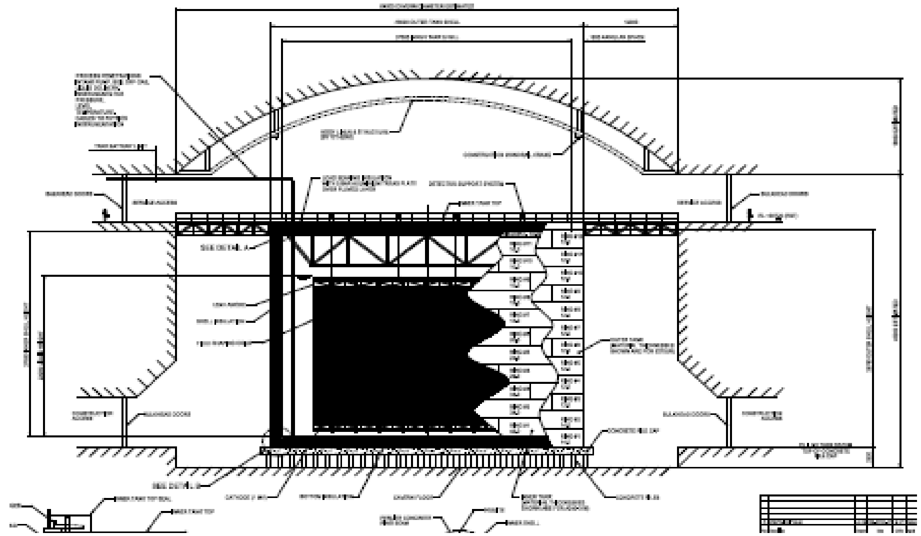
AGT
Italy
INGEGNERIA

Greece
ΔΗΜΟΚΡΙΤΟΣ

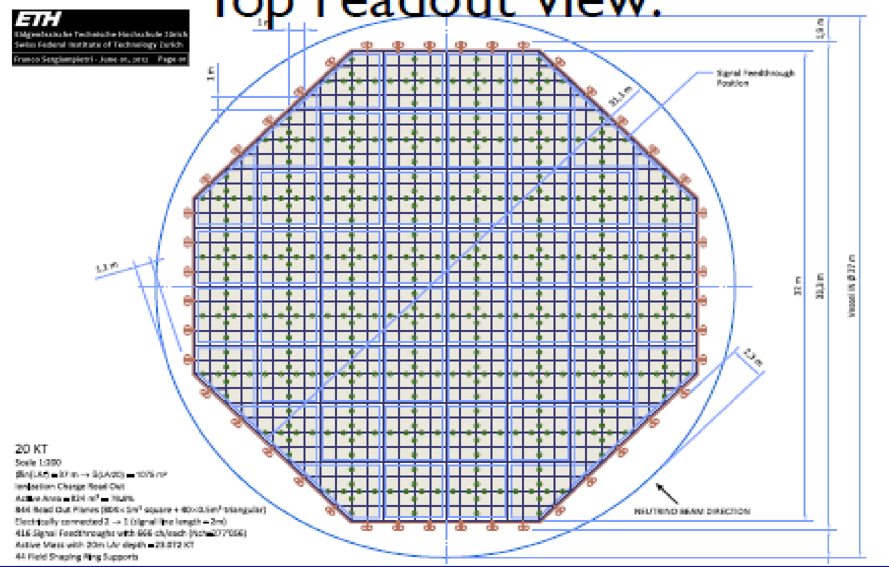


GLACIER detector design

- Concept unchanged since 2003: Simple, scalable detector design, from one up to 100 kton (hep-ph/0402110)
- Single module non-evacuable cryo-tank based on industrial LNG technology
  - industrial conceptual design (Technodyne, AAE, Ryhal engineering, TGE, GTT)
  - two tank options: 9% Ni-steel or membrane (detailed comparison up to costing of assembly in underground cavern)
  - three volumes: 20, 50 and 100 kton
- Liquid filling, purification, and boiloff recondensation
  - industrial conceptual design for liquid argon process (Sofregaz), 70kW total cooling power @ 87 K
  - purity < 10 ppt O_2 equivalent
- Charge readout (e.g. 20 kton fid.)
  - 23'072 kton active, 824 m^2 active area
  - 844 readout planes, 277'056 channels total
  - 20 m drift
- Light readout (trigger)
  - 804 8" PMT (e.g. Hamamatsu R5912-02MOD) WLS coated placed below cathode
- The concept and the designs are reaching the required level of maturity for submission to SPSC.



Top readout view:



Technical aspects finalized in the LAGUNA-LBNO study as deliverables including detailed costing → August 2014 **<u>Affordable</u> <u>underground</u> detector**

LAGUNA-LBNO DESIGN CONTENT

FULLY COVERED CONCEPTUAL DESIGN STUDY
→ INCLUDING:

-GENERAL DESIGN
- -COMPLETE AND COHERENT LAYOUT DESIGN OF THE UNDERGROUND
- -DESIGN OF ON-SURFACE INFRASTRUCTURE
- -LOGISTIC DESIGN + EQUIPMENT OF THE DIFFERENT CONSTRUCTION STAGES
- -IMPLEMENTATION INTO CURRECT INFRASTRUCTURE (MINE / ROAD)
- -SAFETY (H&S) DESIGN FOR REALISATION AND OPERATION

-DESIGN OF THE CAVERNS
- -ROCK ENGINEERING AND EXCAVATION
- -CIVIL WORKS (HVAC + AUXILIARY CONSTRUCTIONS)

-DESIGN OF EXPERIMENT
- -TANK CONSTRUCTION DESIGN + SCAFFOLDING
- -DETECTOR DESIGN AND INSTRUMENTATION
- -ELECTRONICS
- -LIQUID INFRASTRUCTURE, HANDLING + COMMISSIONING

-CONSTRUCTION PROGRAMMES OF ALL STAGES
-RISK ASSESSMENTS + PROJECT RISK REGISTRY + CONTINGENCY
-CONSTRUCTION + OPERATIONAL COSTINGS

LAGUNA-LBNO FIELDS OF INNOVATION

DESIGN (REALIZATION STEPS)

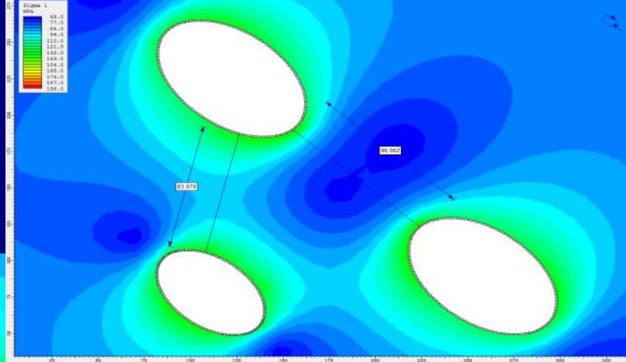
- GEOLOGICAL ENGINEERING
- ROCK ENGINEERING
- MINE ENVIRONMENT
- HEATING, VENTILATION, AIR CONDITION

- TANK TECHNOLOGY UNDERGROUND
- CONCRETE WORKS
- MEMBRANE TECHNOLOGY
- SIGNAL FEED-THROUGHS
- CONSTRUCTION LOGISTICS + CRANEAGE
- INSTALLATION LOGISTICS

- LIQUID ARGON DETECTOR
- SCAFFOLDING
- CLEAN ROOM DEMANDS
- INSTALLATION TOLERANCES
- SPECIAL CONSTRUCTION MATERIALS
- ELECTRONICS + DATA AQUISITION

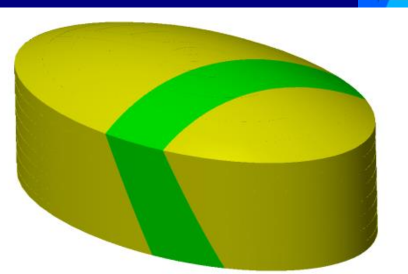
- LIQUID INFRA-STRUCTURE
- LIQUID TRANSPORT
- LIQUID HANDLING
- SLIM STEEL CONSTRUCTION
- HIGH VOLTAGES (UP TO 2MV)

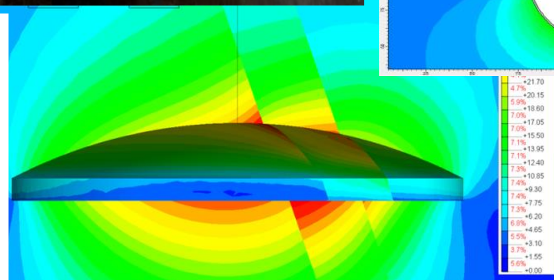
- HEALTH AND SAFETY QA
- RISK ASSESSMENTS QA
- COST OPTIMIZATION
- PROJECT MANAGEMENT



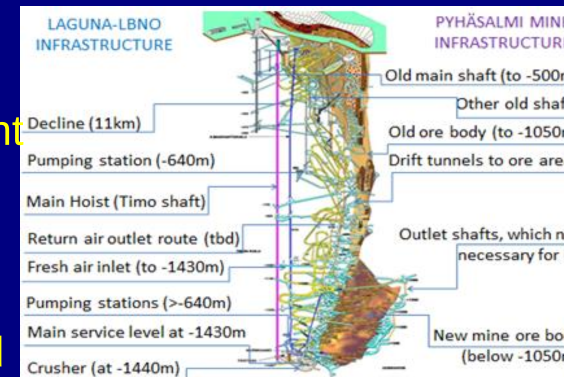
Rock engineering
Caverns:
- ✓ 64m span,
- ✓ 100 m length,
- ✓ 38 m height

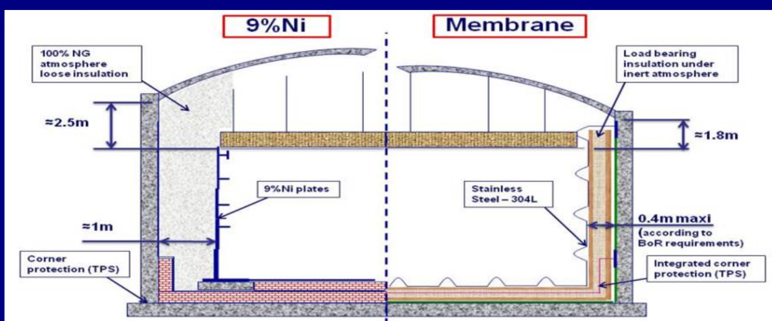
at 1400 m dept.





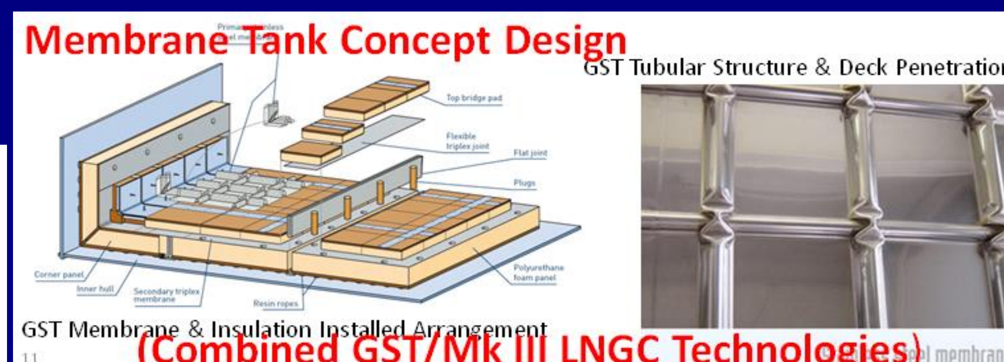
- Infrastructure integration with mine environment
- Concrete production

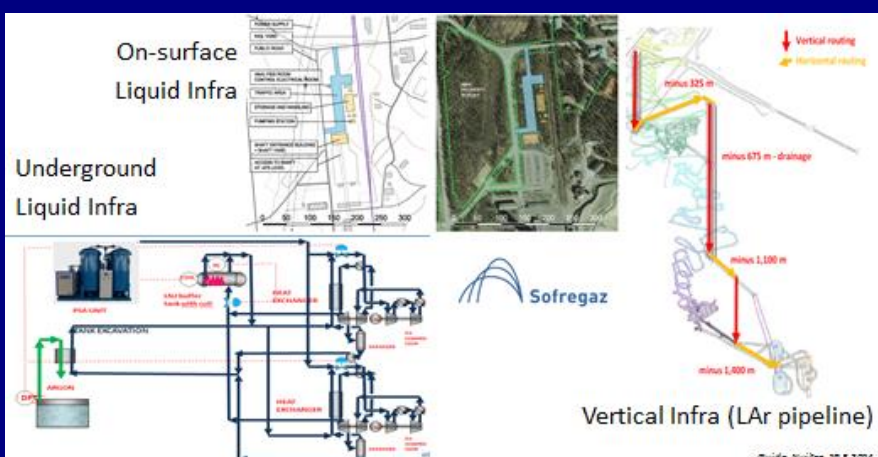




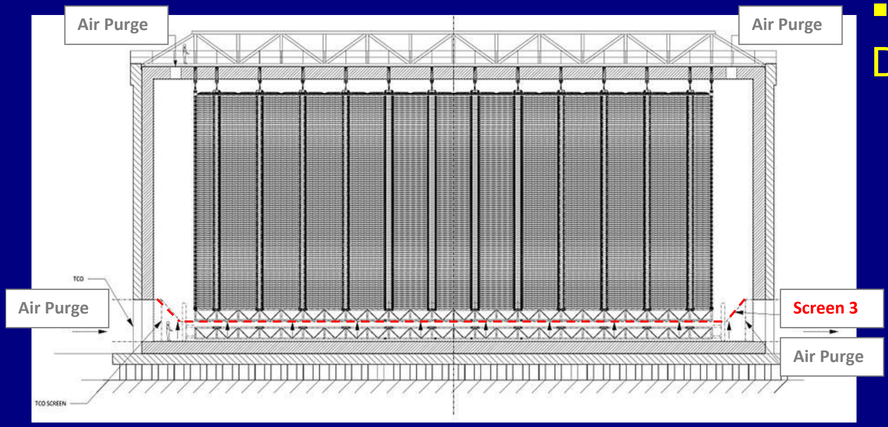
- Study of single/double containment underground

→ Membrane tank double containment



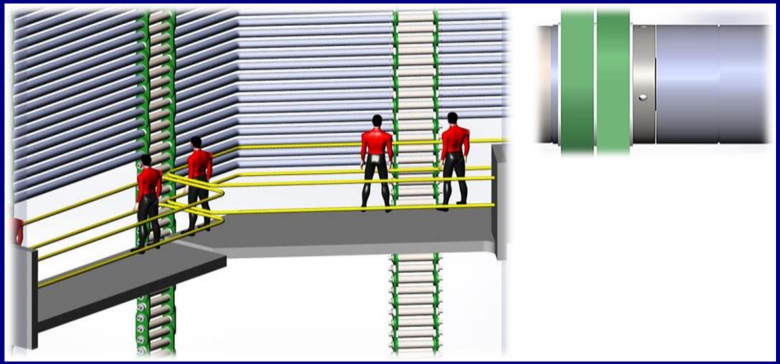


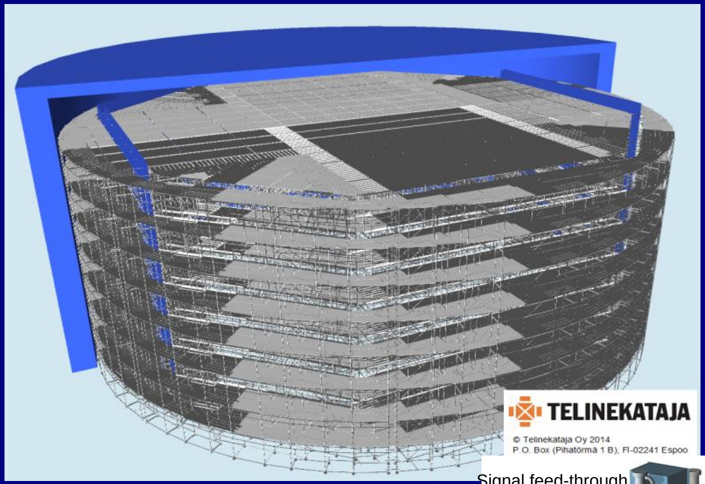
- Design and integration of the liquid handling infrastructure
- Liquid procurement, safety, risk assesment



- Construction/Installation

Design and detailed logistics of the construction steps

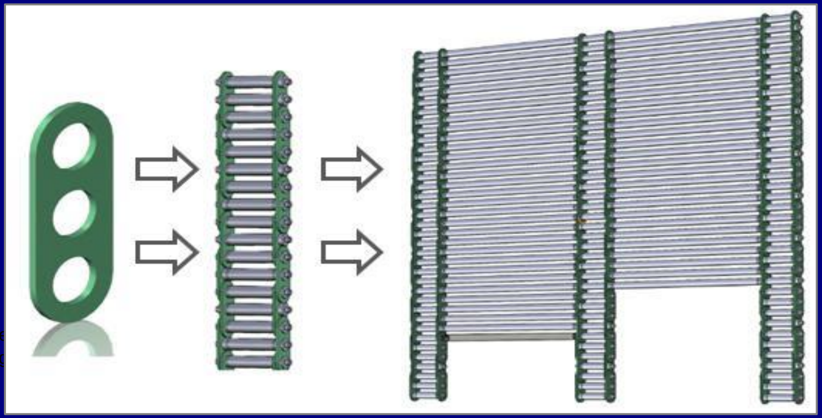


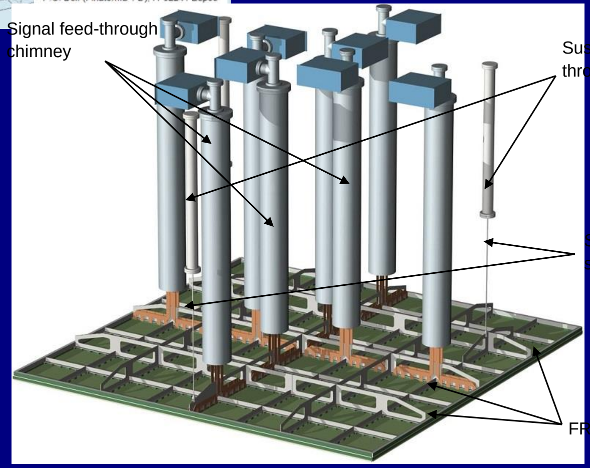


- Special construction materials and demands

Field cage, cathode, anode deck and feed-throughs

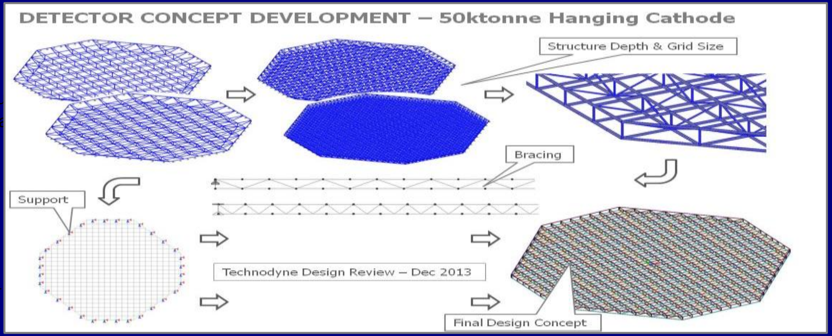
- Scaffolding
- Clean room integration





And last but not least:

- Double phase detectors design and integration
- FE electronics and DAQ
- VHV



- LBNO design phase concluded

→ Outcome: optimized configuration for a LBL experiment studied in Europe (as recommended by CERN, APPEC) with associated technological developments, innovative solutions and full costing

- Deliverables to the EC, outcome of the design study, documented in >4000 pages (0.5 GB)

- Final design study meeting in Helsinki (24-28 August 2014)
- Conclusions of that meeting are represented in this presentation

→ Explore the application of all these developments for a US hosted experiment

- First step: assessment meeting at Homestake (8-10 October) in collaboration with the industrial partners in order to understand the feasibility of LBNO-like detector

LBNO costs from design study deliverables

Element	20 kton (Meur)	20+50 kton (Meur)
Excavation Work (Tunnels and Caverns)	38,7	57,8
Civil Works & Underground infrastructure	9,4	12,3
Membrane Tank	45,4	117,4
Detector	41,5	111,8
Liquid Infrastructure Equipment	40,4	52,6
Liquid Argon	26,3	86,0
Contingency (Risks)	24,7	45,5
Total	226,4	483,4

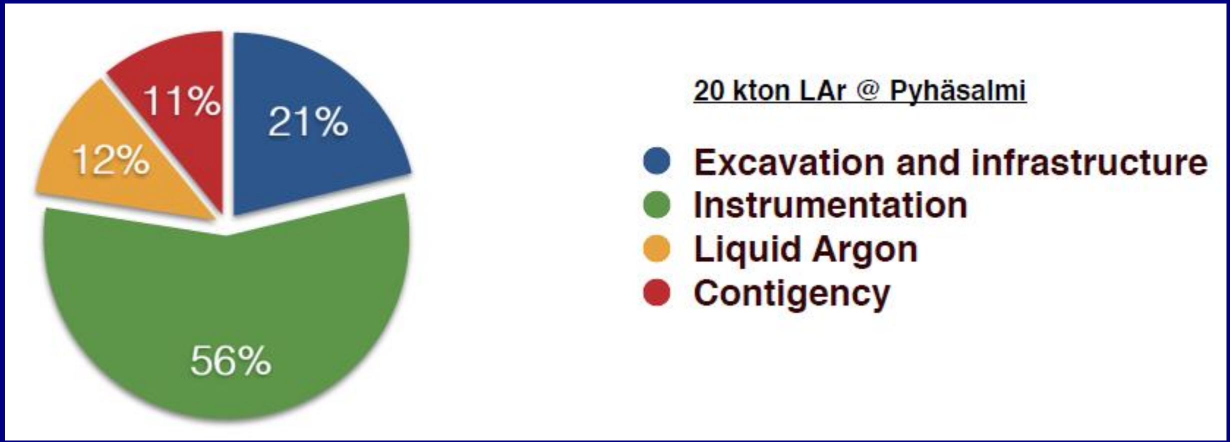
~126 Meur

Costs are evaluated with the industrial partners "key in hands" including manpower

How much are they dependent from the optimization provided by the Pyhasalmi site and by the careful technological choices ?

For which aspects are they exportable/implementable in the US ?

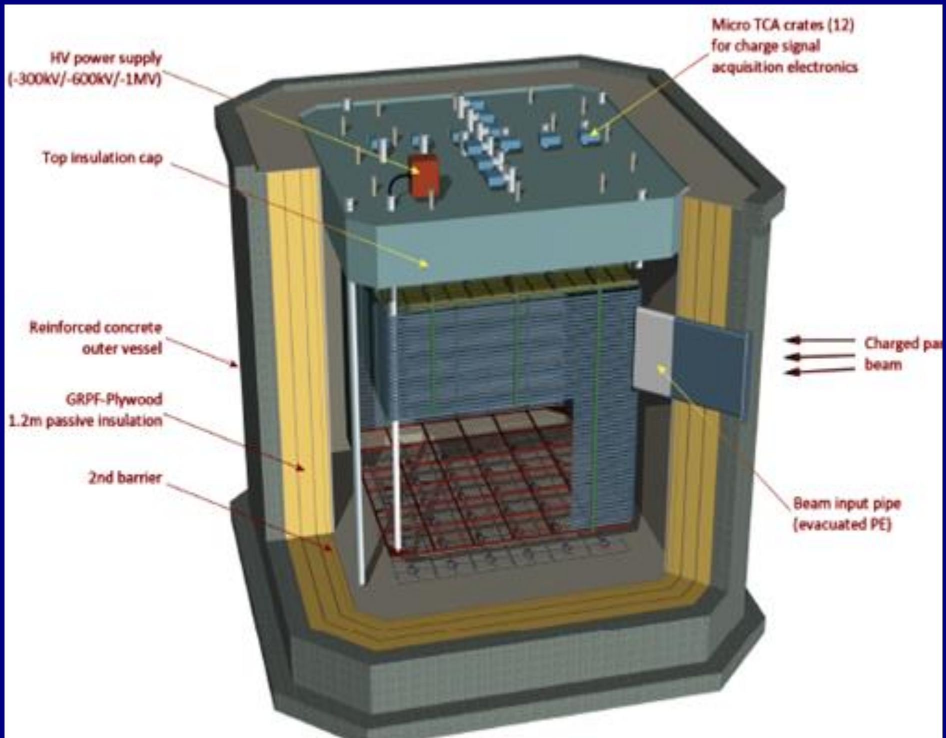
Staged physics/construction approach 20/50 kton
→ limited resources for the first phase



Detailed evaluation of contingency by risk analysis

→ 9 years and 226Meur needed for the construction of the 20 kton detector

The LBNO-DEMO/WA105 experiment at CERN



Liquid argon density	T/m^3	1.38
Liquid argon volume height	m	7.6
Active liquid argon height	m	5.99
Hydrostatic pressure at the bottom	bar	1.03
Inner vessel size (WxLxH)	m^3	$8.3 \times 8.3 \times 8.1$
Inner vessel base surface	m^2	67.6
Total liquid argon volume	m^3	509.6
Total liquid argon mass	t	705
Active LAr area	m^2	36
Charge readout module (0.5 x0.5 m^2)		36
N of signal feedthrough		12
N of readout channels		7680
N of PMT		36

→ 1/20 of 20 kton LBNO detector

6x6x6m^3 active volume, 300 ton , 7680 readout channels, LAr TPC (double phase+2-D collection anode).
Exposure to charged hadrons beam (0.5-20 GeV/c)

Full-scale demonstrator of all innovative technologies studied in LAGUNA-LBNO for a large and affordable underground detector:

- **LNG tank construction technique (with non evacuated detector)**
- **Purification system**
- **Long drift**
- **HV system 300-600 KV**
- **Double-phase readout**
- **Readout electronics**

Assess the TPC performance in reconstructing hadronic showers (the most demanding task in reconstructing neutrino interactions):

- **Measurements in hadronic and electromagnetic calorimetry and PID performance**
- **Full-scale software development, simulation and reconstruction to be validated and improved**

Installation in the CERN NA EHNA extension, data taking in 2017
→ Fundamental step for the construction of a final LBNO-like detector

A PILOT experiment

Underground implementation of a pilot detector at the 2.5-5kton scale, based on detector modules ***doubling*** LBNO-DEMO inner active dimensions ($12 \times 12 \times 12 m^3$)

→ Physics demonstrator (as recommended by P5) and direct testing of all the aspects related to the underground installation and operation

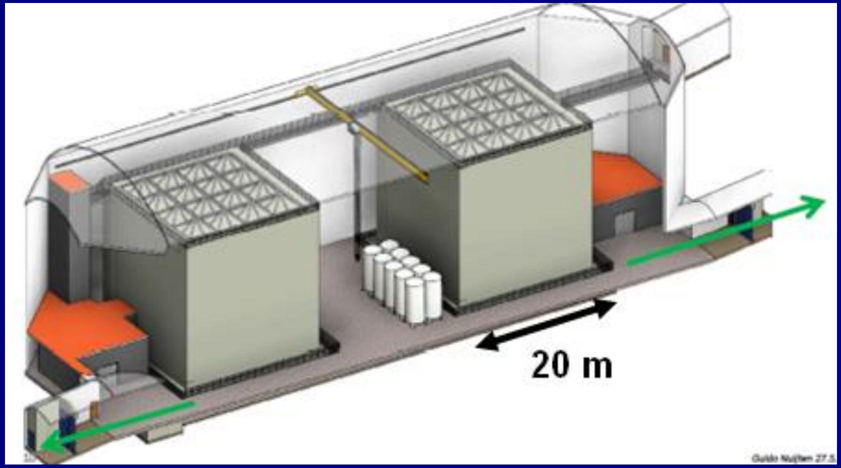
Estimated event rates:

➡ SN observatory (5'000 events for d=5 kpc)!

➡ atmospheric neutrinos (≈1000 numu/nue/CC+NC events/year and ≈5 nutau CC/year) – "SubGeV" much better than in SK!

➡ proton decay (20 kton x yr is competitive with SK in p→nu+K and many other multiple particle final states)!

➡ LBL beam ? MH early determination possibility



→Essential intermediate step with interesting physics program and thorough study of underground physics cosmic rays backgrounds

- Full cost ~50 Meuro (evaluated for Pyhasalmi, including excavation and civil engineering)
- Construction timescale ~4 years

LBNO physics strategy

- Select a very long baseline (2300km and optimized site for installation) to explore <u>the L/E pattern </u>predicted by the 3 flavor mixing mechanism <u>over the 1st and 2nd max.</u>
- Staged experiment adjusting the beam and detector mass on the bases of the findings of the first phase, most efficient use of resources:

- **Phase I (LBNO20)**

  24 kton DLAR + SPS beam (700 kW, 400 GeV/c), 15E20 pot, 25% antinu
  Guaranteed 5σ MH determination +46% CP coverage at 3σ + proton decay + astroparticle physics

- **Phase II (LBNO70)**

  70 kton DLAR + HPPS beam (2 MW, 50 GeV/c) 30E21 pot, 25% antinu or Protvino beam, 80% (65%) CP coverage at 3σ (5σ) + proton decay + astroparticle physics

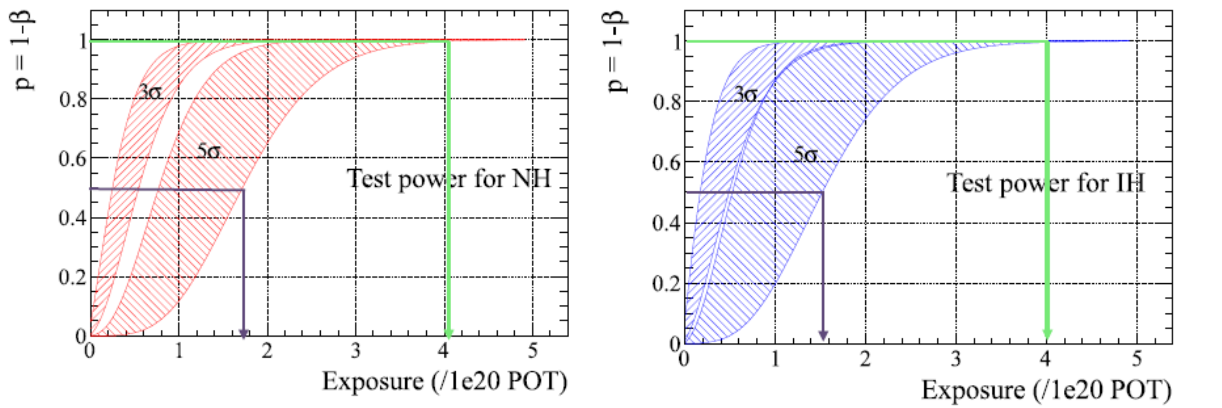
- Complementarity to HyperK (numu vs ant-inumu at first max, 300 km) → L/E dependence at 2300 km, 25% antinumu. matter effects

- L/E pattern measurement releases requirements on systematic errors related to the rate normalization at the first maximum

→ Guarantee MH at 5σ and incremental CP coverage satisfying the P5 requirements

- Power vs exposure for all values of δ_{CP} (shaded bands)

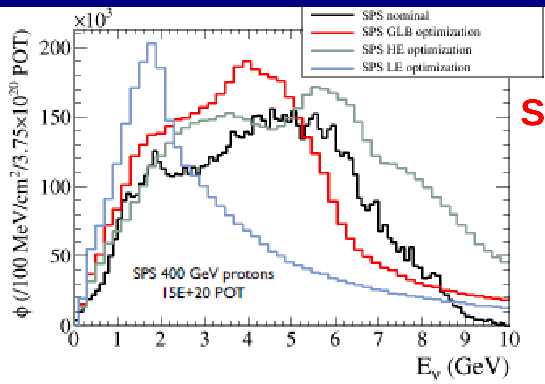
arXiv:1312.6520



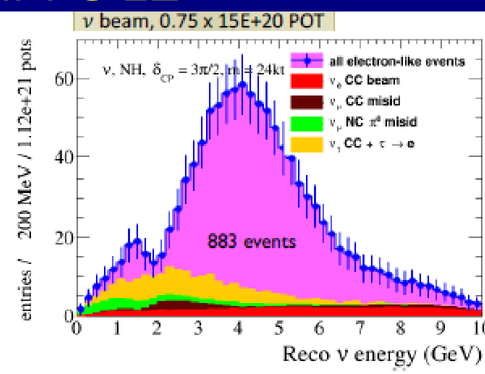
MH determination:

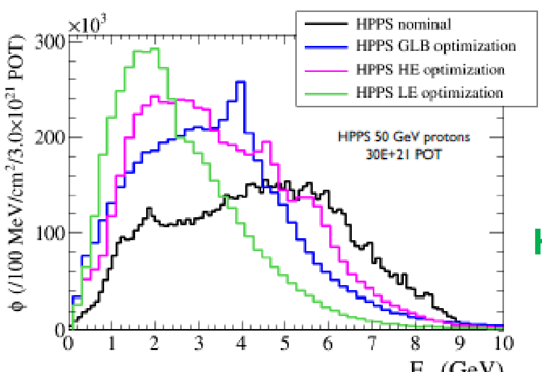
- ✓ Median 5σ C.L. (p=0.5) reached within 2 years of SPS operation at 750kW.
- ✓ Guaranteed 5σ C.L. (p=1) reached within 5 years of SPS operation at 750kW.

Beam optimization for CP violation → best CP coverage obtained for: « SPS GLB » and « HPPS LE »

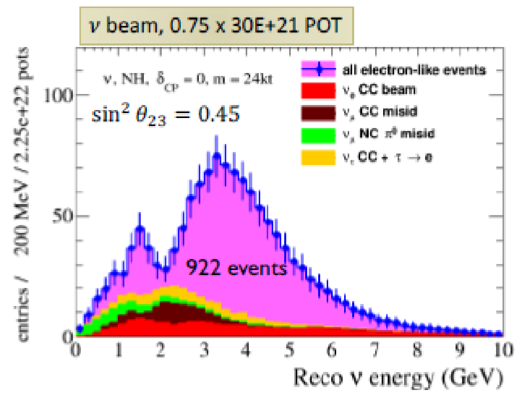


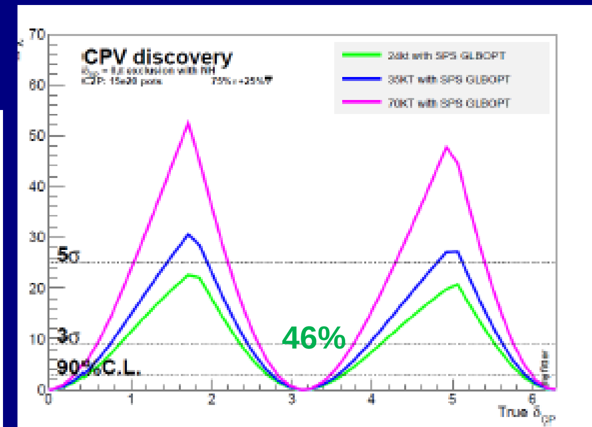
SPS GLB

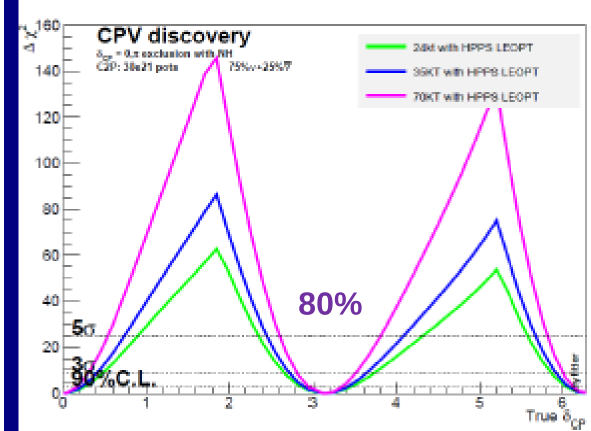


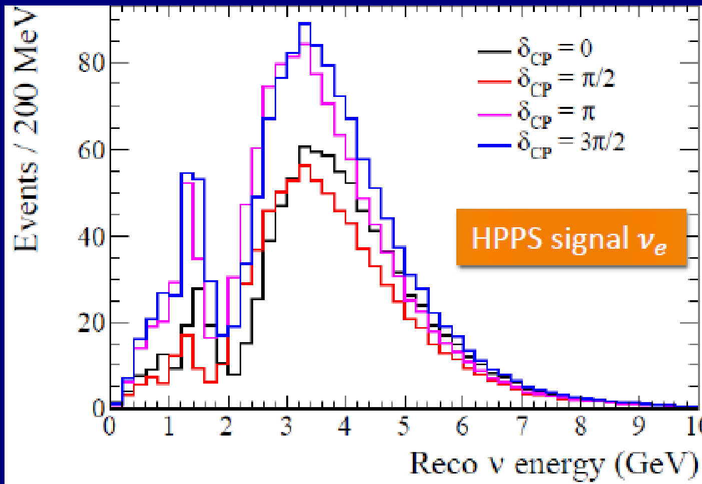


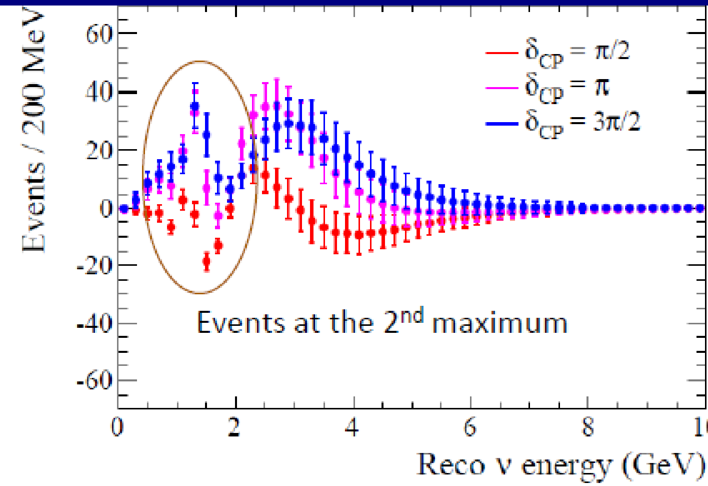
HPPS LE











Rich features in the region of 2nd max

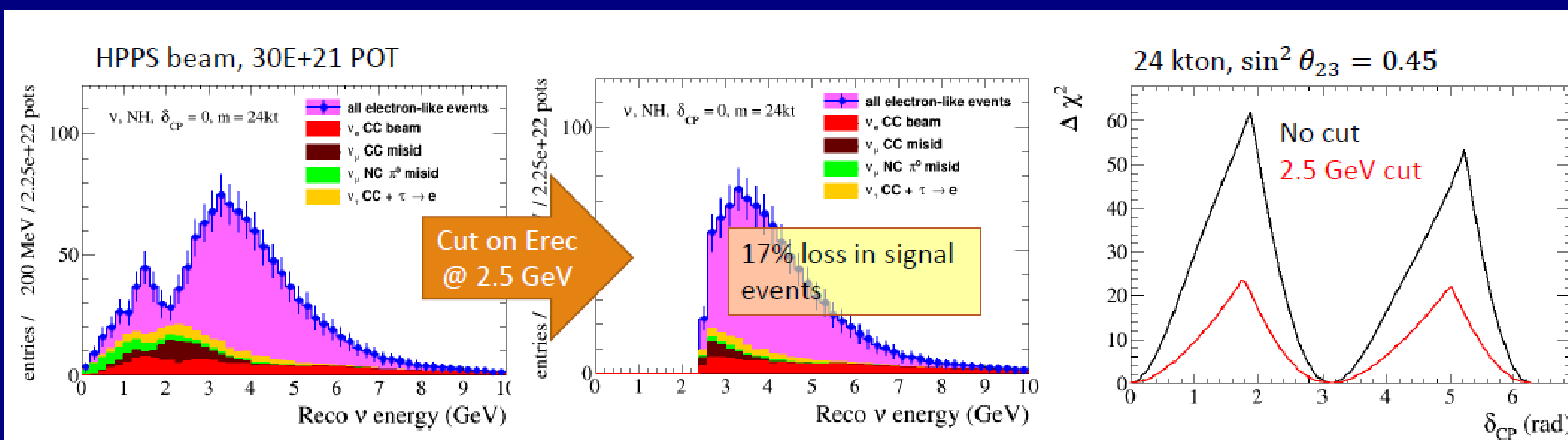
→ Less critical on normalizazion syst for 1st max

Cut at 2.5 GeV removes 17% (5%) of events for the HPPS (SPS) beam with a dramatic loss of sensitivity:

Median coverage

	$F_{3\sigma}$	$F_{5\sigma}$
24 kton	69% → 41%	43% → 0%

Parameter	Value	Error
Signal normalization (f_{sig})	1	3 %
Beam electron contamination normalization ($f_{\nu e}$)	1	5 %
Tau normalization ($f_{\nu \tau}$)	1	20 %
ν NC and νμ CC background (f_{NC})	1	10 %



LBNF as seen from LBNO:

❖ It represents an strong opportunity:

- P5 and US HEP community support to the fundamental physics case related to MH and CP violation and underground physics

- Future availability of 1.2 MW proton beam at Fermilab (PIP II)

- DOE funding commitment for LBNF “highest priority experiment” (past evaluations based on 34kton at Homestake)

❖ It implies a series of open questions we are trying to understand:

(being addressed by the ongoing work of the IIEB, to which we are very glad to contribute)

1) The DOE funding commitment on LBNF is a large amount of money, comparable to the cost of a LHC detector:

- Which is the breakdown of the actual cost estimates ?
- Can the « performance/funding » ratio be optimized on the basis of the experience of LBNO ?
- How much of the LBNO design/costing is exportable to an experiment hosted in the US or site specific ?

2) Can we jointly design the best possible experiment, Fermilab hosted, with ambitious physics goals, as recommended by P5 ?

« the experiment that everybody would like to do, the experiment which will not risk to arrive second »

→ This possibility is deeply related to the scientific strategy discussion, the baseline/site optimization, the technological strategy

- LAGUNA-LBNO was a purely science driven effort. Under the mandate of CERN and APPEC, LAGUNA-LBNO has been intensively working on an optimized experiment in Europe in order to address these physics questions and it has successfully completed the Design Study phase commitment to the EC.

- Following the global strategy, the LAGUNA-LBNO community is now committed to explore, on the basis of the outcome of the DS, the possibility of building a Fermilab hosted experiment of comparable performance and with comparable costs to LBNO. (Physics is fortunately translations invariant, technical issues have to be assessed)

- It is important to understand the feasibility of a LBNO-like detector at Homestake and/or in alternative sites with horizontal access. A first practical step in this direction will be the visit/meeting at Homestake (8-10 October 2014) checking/discussing several technical aspects.

- The WA105 experiment at CERN (LBNO-DEMO) is starting and it will verify on a full scale test the innovative technologies developed in the LAGUNA-LBNO DS. There is clear path for the detector technology assessment for LBNF.

- A pilot detector installation would represent an important milestone/early startup of the LBNF program, training the community and satisfying the P5 requirements on astroparticle physics performance assessment

- The ongoing process promoted by Fermilab and DOE is moving in the direction of assessing the conditions for the best implementation of LBNF.

- It is a big challenge for the IIEB to find a working scheme to solve all the open questions and determine the best scientific and technological/site strategy for a Fermilab hosted experiment

  → IIEB discussions and work and WGs operation in the following months

- The LBNF program is a huge investment/responsibility

  → This investment will have to result in an aggressive scientific strategy and an efficient use of resources

Support to the neutrino physics case: MH, CP

Neutrino Oscillation Experiments (Program)

- Short- and long-baseline oscillation experiments directly probe three of the questions of the neutrino science Driver:
  - How are the neutrino masses ordered? Do neutrinos and antineutrinos oscillate differently? Are there additional neutrino types and interactions?
- There is a vibrant international neutrino community invested in pursuing the physics of neutrino oscillations.
- The U.S. has unique accelerator capabilities at Fermilab to provide neutrino beams for both short- and long-baseline experiments, with some experiments underway, and a long-baseline site is available at the Sanford Underground Research Facility in South Dakota.
- Many of these current and future experiments and projects share the same technical challenges. Interest and expertise in neutrino physics and detector development of groups from around the world combined with the opportunities for experiments at Fermilab provide the essentials for an international neutrino program.

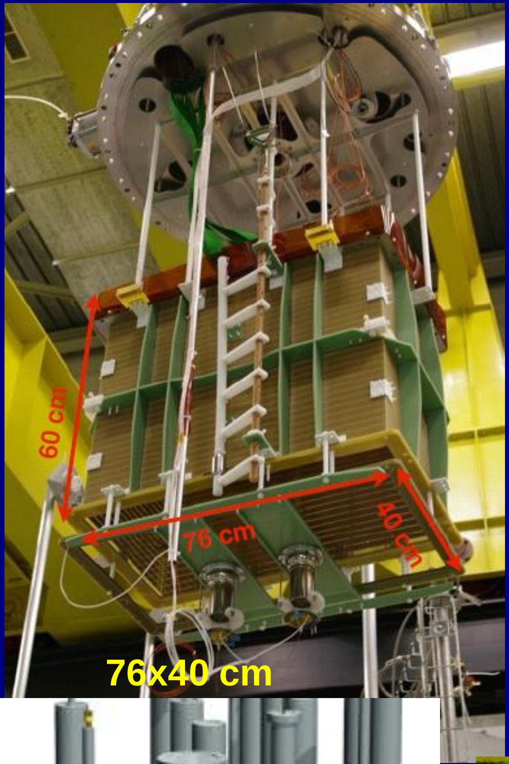
- **Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.**

Support to high intensity beams , PIP II

Neutrino Oscillation Experiments (PIP-II)

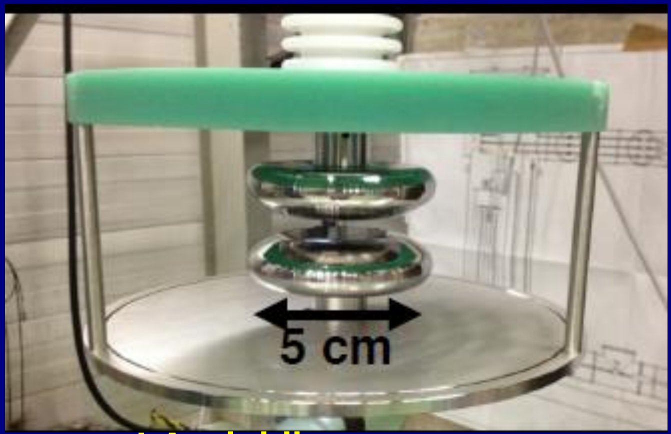
- The PIP-II project at Fermilab is a necessary investment in physics capability, enabling the world's most intense neutrino beam, providing the wideband capability for LBNF, as well as high proton intensities for other opportunities, and it is also an investment in national accelerator laboratory infrastructure. The project has already attracted interest from several potential international partners.
- **Recommendation 14: Upgrade the Fermilab proton accelerator complex to produce higher intensity beams. R&D for the Proton Improvement Plan II (PIP-II) should proceed immediately, followed by construction, to provide proton beams of >1 MW by the time of first operation of the new long-baseline neutrino facility.**

Parallel ongoing technical R&D activities:

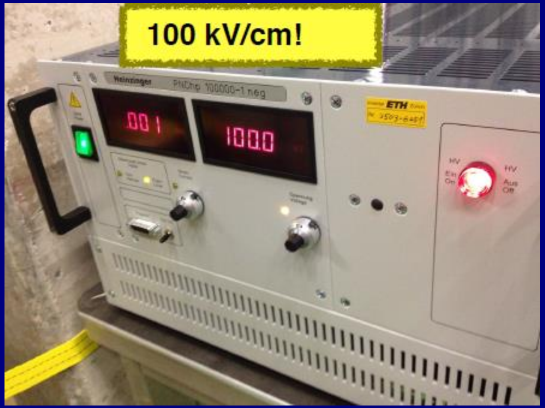


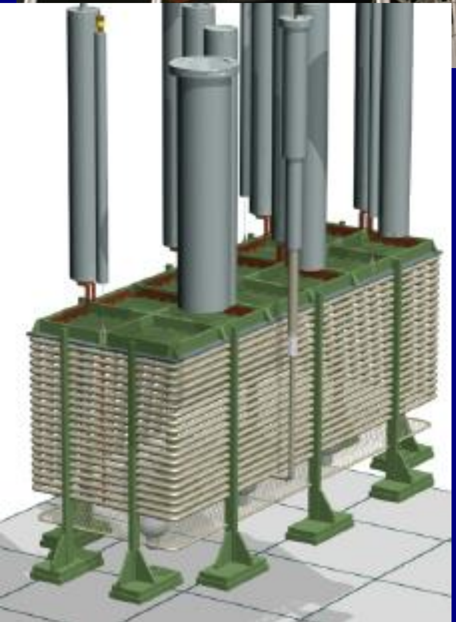
76x40 cm

10x10x20 cm
LEM-anode fast test setup

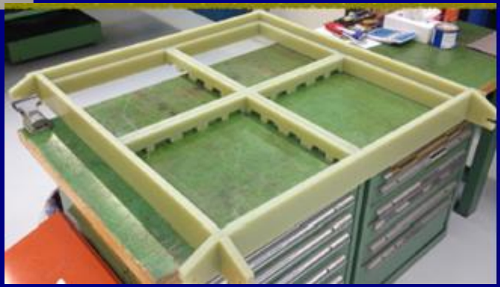


LAr rigidity test setup





3x1x1 m
(3 CRP)



CRP mockup

Readout test setup in Lyon